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Abstract: Study of Mobile Ad hoc Networks is a very up-to-date topic. A lot of research studies have been carried out with a special emphasis on routing protocols. In the meantime access protocols designed for multihop ad hoc networks receive less consideration. While in wired network the benefit of carrier sensing has been shown to be very significant [1], in multihop ad hoc networks this benefit can be questionnable since hidden collisions are known to significantly degrade performance of CSMA (Carrier Sense Multiple Access) protocols [2]. Using a simple but realistic model, we compare the global throughput of CSMA protocols and Aloha in mulihop ad hoc networks. To maintain this comparison, we assume an isotropic progation without obstacles and network nodes locations following a Poisson process. We compare results of this model with simulations. We show that, actually, carrier sensing improves the global throughput. This result could be thought to be in contradiction with a previous study [3]. The reason of this apparent contradiction is explained.

Key-words: Ad hoc Network, performance evaluation, CSMA protocol, routing protocol, interference, IEEE 802.11, hidden nodes, spatial reuse.

(Résumé : tsvp)

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Comparison du débit d'Aloha et de CSMA dans un réseau mobile ad hoc CSMA multisaut

Résumé : De nombreuses études ont été menées sur les protocoles de routage dans les réseaux ad hoc et spécialement à l'IETF dans le groupe de travail MANET. Ces études concernent principalement la conception de protocoles de routage pour des réseaux mobiles. Dans le même temps, la conception de protocoles d'accès pour les réseaux ad hoc multisaut a reçu beaucoup moins d'attention. Alors que dans les réseaux filaires le bénéfice de la détection préalable de porteuse est important [1], dans les réseaux ad hoc multisaut ce bénéfice peut être remis en cause car les noeuds cachés peuvent dégrader très significativement les performances du CSMA (Carrier Sense Multiple Access) [2]. En utilisant un modèle simple mais réaliste, nous comparons le débit global du CSMA et d'Aloha dans le contexte de réseaux ad hoc multisaut. Pour réaliser cette comparaison, nous supposons une propagation isotrope sans obstacle et une distribution de Poisson spatiale pour les noeuds du réseau. Nous comparons les résultats de ce modèle avec des simulations. Nous montrons qu'en fait la détection de porteuse améliore le débit global. Ce résultat peut sembler en contradiction avec une étude précédente [3]. La raison de cette apparente contradiction est expliquée.

Mots-clé : Réseau ad hoc, évaluation de performance, protocole CSMA, protocole de routage, interférence, standard IEEE 802.11, noeuds cachés, réutilisation spatiale.

1 Introduction

The major progress in wireless modem has opened a new technical area around Wireless LAN e.g. IEEE 802.11 [4], HiPERLAN [5], Bluetooth. Mobile ad hoc networking is a new research area which has benefited from this emerging wireless technology. Contrary to LANs where the propagation constraints do not usually impose stringent restrictions, in WLANs the transmission range is very limited. The network connectivity has to rely on a routing algorithm which allows packet exchange between nodes not directly within radio reach, see figure 1. Thus, in ad-hoc networks, the routing issue is a key issue. This area has received a strong interest from the academic world. At the Internet Engineering Task Force (IETF) a new working group MANET (Mobile Ad hoc NETwork) started in 1997. This group has produced numerous routing proposals [6, 7, 8, 9]. Many publications have compared various routing algorithms for ad-hoc networks.

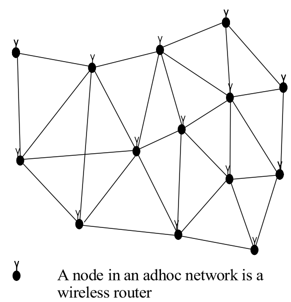

Figure 1: An ad hoc network which needs routing to ensure a proper connectivity

Another key issue which has received much less attention is the design of access schemes to be used in ad hoc networks. Due to the genuine multihop property of ad hoc network a packet has to be retransmitted to reach its final destination. This leads to potential simultaneous transmissions in the network with the risk of collision with distant transmitters or incurred by the cumulative effect of simultaneous transmissions. In usual single hop network, it has been shown that a prior carrier sense of the channel (CSMA) actually significantly improves the performance of pure Aloha techniques [1]. In a multihop environment context a previous work (and to the authors' best knowledge the first study to have investigated in the area of access schemes in mulihop networks) has shown that contrary to the figures in a single hop network CSMA and Aloha have in a multihop context similar performances. This is precisely the aim of this article to compare Aloha with CSMA protocols in the context of ad hoc networks.

This paper is organized as follows: the next section introduces related works and introduces our study. In particular in this section we will answer the following questions: why is it interesting to consider CSMA protocols as they are usually thought not to be useful for wireless network because unable to cope with hidden collision. We will also explain why

Aloha can be thought to outperform CSMA in a multihop network. In section 3, we develop a simple static model to compare Aloha and CSMA multihop network and we compare CSMA and Aloha on the basis of this model. Section 4 is devoted to a dynamic simulation of Aloha and CSMA which confirms the results of the static model.

2 State of the art and related works

There are two strategies to share a medium. In the first one, called controlled access, the sharing is organized on a predetermined basis; this is the strategy used in TDMA protocols. The alternate strategy is the random access technique, Aloha and CSMA protocols are in the direct line of this approach. An excellent summary of approaches to multiple access can be found in [1]. Due to the genuine mobile and open characteristics of ad hoc networks, it is generally admitted that a random access technique must be used. CSMA (Carrier Sense Multiple Access) protocols have been widely studied in wireless LANs [1]. In wireless networks where all the nodes are within carrier sense reach it can be shown that this technique offers a significant improvement over the simple Aloha scheme where packets are sent without any prior carrier sensing. However a wireless network where nodes are not mutually within carrier sense reach will suffer from the hidden nodes collisions problem. The hidden node collision is a situation in which an on going transmission is spoiled by a simultaneous remote transmission or by the cumulative effect of such distant transmissions. This very transmission although being ruled by CSMA can not detect the ongoing transmission. After the initial paper from Tobabgi [2] numerous papers mostly in the 90s proposed dedicated protocols to cope with this problem [10, 11, 12, 13, 14]. The general idea of these protocols is to implement a mechanism in the receiver to protect its reception. The receiver warns its neighbor nodes of its on going reception. Thus the carrier sense is extended around the receiver creating an additional exclusion area in which stations will not be allowed to start a transmission. In figure 2 we have represented an example of such a technique: the RTS/CTS mechanism which is an option in the IEEE 802.11 standard. When a network node intends to send a point to point packet, the source node sends prior to the data packet a small packet called RTS packet, RTS stands for Request To Send. If this very packet is correctly received by the receiver and if the receiver is ready to receive a new packet, this node answers to the source node by a small packet called CTS (for Clear To Send). If the CTS packet is also successfully received by the source node, this node starts transmitting its data packet immediately after the reception of the CTS. Additionally both the RTS packet and the CTS packet carry the total duration of the foreseen transmission, this information is given in the NAV (Network Allocation Vector), see[4]. Thus all the nodes within transmission range from the transmitter and the receiver are aware of the duration of the foreseen transmission and cannot start a transmission in this time window. Of course this mechanism complements the usual carrier sense. Thus depending on the carrier sense threshold and on the actual transmission range, the exclusion area incurred by the NAV can be included in the standard carrier sense exclusion area or can complement this area.

Figure 2 represents such a situation. Of course this figure assumes that the propagation is isotropic with no obstacles which is precisely an assumption that we will use in this study.

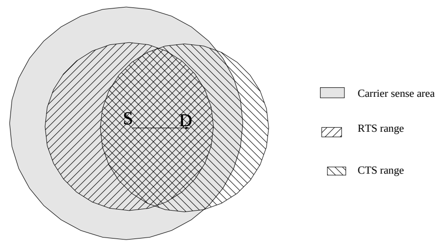

Figure 2: Carrier sense range, RTS and CTS range

With such an assumption the carrier sense level can always be tuned to offer an exclusion area including the extra exclusion area created by the NAV scheme. That is the reason why we will consider in the present work only a simple CSMA protocol without additional feature. However it must be well understood that the enhanced access schemes described in [10, 11, 12, 13, 14] can be very useful in the context of non isotropic propagation for instance in a network showing obstacles to free radio propagation (steel, concrete...). These proposals will be also useful for long packets since they reduce the cost of a collision.

In a recent paper [15] Gupta and Kumar show that the actual throughput in a multihop wireless network with n randomly located nodes is actually $O(W/\sqrt{nlog(n)})$ where W denotes the bandwidth in bit/s. At to the authors best knowledge this paper was the first attempt to evaluate the total throughput of an ad hoc network. This initial study has motivated further contributions to evaluate the global through of ad networks. In [16] the global throughput is evaluated for regular ad hoc networks. The work carried in [17] relates to scheduling properties of IEEE 802.11 in ad hoc networks and show that ad hoc network can scale if the traffic remains local. An important conclusion can be drawn from [15]; the medium sharing is the limiting factor in ad hoc networks. A key figure in an ad hoc network is then the achievable number of simultaneous successful transmissions. In a CSMA protocol, the carrier sense threshold will be the key parameter to rule the number of potential simultaneous transmissions. Of course to compute the actual global network throughput we have to evaluate for a given carrier range the probability that this transmission is not spoiled by the interference caused by the other simultaneous transmissions. In such a case a legitimate question can be the following: does the carrier sense technique show better performance than the completely statistical selection that is operated in a pure Aloha protocol. That is precisely the question under examination in the present contribution. Obviously to carry out a fair comparison both CSMA and Aloha must be optimized.

3 Assumptions and models for CSMA and Aloha

This section is divided in four main parts. The first part is devoted to presenting the general assumptions concerning radio propagation, packet capture and the network. The second section presents the CSMA model. The third section presents the Aloha model. The last section reports results from the models both for CSMA and Aloha.

3.1 Assumptions

Let us assume that all the network nodes will transmit with the same power P_0. We will use the following function $P(r) = \frac{P_0}{r^\alpha}$ to compute the power $P(r)$ at distance r; α is usually called the decay factor.

There is another very classical assumption concerning correct reception of a packet. It is usually assumed that a correct transmission implies two conditions. The first one is that the signal strength of the received transmission is above a given threshold P_{thres}. The second one is that the ratio of the signal strength by the interference is greater than the capture level. This condition is known to be the SIR (Signal over Interference Ratio) criteria. The interference I experienced by the transmission is the sum of the thermal noise and of the concurrent transmissions. In the following, we will denote by K the capture level. We can summarize the two conditions ruling the capture of a packet

$$P(r) \geq P_{thres} \text{ and } \frac{P(r)}{I} \geq K.$$

Two different interference models are widely used.

In the first and simplest one, we only consider the strongest interferer to decide if the reception is correct or not. In this model we assume that the capture condition is to be verified for the interferer with the maximum power strength. This condition is widely used in simulation works. For instance it is the one that is implemented for the IEEE 802.11 protocol model in the ns simulator [18], thus all the simulation works using this tool actually are under this simple model!

The second model is the total interference model. In the total interference model the contribution of all the interferers are taken into account. The condition to receive a packet is thus

$$\frac{P(R)}{\sum_i P(r_i)} \geq K.$$

where i denotes the interferer and r_i denotes the distance between the receiving node and the interfer i. The interference : $\sum_i P(r_i)$ is often called shot noise. Unless stated, we will use in this work the second model for the interference.

For the network, we use the following assumptions:

- the ad-hoc network is deployed on an area of S square meters (to simplify we will assume that S is infinite or at least large)

- the location of the network nodes follows a Poisson point process of intensity λ,
- for a given node its neighbor nodes will be in a a disc of radius the transmission range R; only neighbor nodes can forward packets for a node,
- the bandwidth (air rate) of the shared radio medium is W in bit/s,
- all the packets have the same size,
- the network node queues are always full,

Additionally, we will assume that the traffic is symmetric, for a given source the destination is randomly selected.

3.2 Model for CSMA

It is well known that in CSMA protocols it is impossible to transmit and receive in the same time. Thus whenever a node A transmits, this node will block the transmission access for other nodes in the vicinity of A. We call this area around A the "carrier sense area". However, the data signal sent by A can not successfully be received in all the exclusion area, the data will be successfully received in a smaller area called the "reception area", the range of this area can be tuned by the carrier sense threshold which determines the level of signal above which a transmission has to be differed. With the isotropic radio model we have assumed, the carrier sense area and the reception area will be disks of radius respectively noted R_{cs} and R, see figure 3.

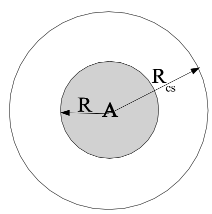

Figure 3: Carrier sense area and reception area

It is also well known that CSMA protocols must incorporate another scheme to schedule transmission. This schedule is usually a simple backoff scheme, this mechanism is useful to designate a transmitter when many nodes are waiting for a free channel to send their packet. Most often CSMA when used on a radio channel also uses an additional mechanism to acknowledge point to point packets at the MAC level. When a packet is correctly received by the destination, this latter sends an acknowledgement packet to inform the source node that the packet has been correctly received. A MAC acknowledgement technique is really important on a radio medium because collisions can not be detected by the transmitting nodes as done on Ethernet. On a radio medium, the power decay is so strong that a transmitting node is dazzled by its own transmission and cannot detect a simultaneous transmission. In this work and especially in the simulation part we will use a CSMA with an additionnal MAC acknowledgement. We will use a simple backoff mechanism. Actually the protocol that we will use for the simulation will be the IEEE 802.11 MAC access mechanism without the RTS/CTS option.

Although CSMA protocol is inherently not a slotted protocol we will adopt a slotted model. This model is justified in the framework of our assumptions by the following remarks. In our ad hoc network packets are transmitted following the CSMA rule. Thus except for "simultaneous" transmission (starting within a small collision window) all the other nodes simultaneous transmitting are at least R_{cs} apart. Thus the network activity can be seen as a succession of transmissions of nodes distant from at least R_{cs} and each transmission is of the same duration according to our assumption of constant packet size. Thus everything takes place as if the network activity was a succession of slots in which stations not within carrier sense reach are sending their packet, see figure 4 in which we are sampling simultaneous transmission in a square area of the network. To take into account the back off and the acknowledgement duration, we will add the mean duration of the back off to the packet duration as well as the duration of the acknowledgement and the duration of the IFS (Inter Frame Spacing) between packets and between the packet and its acknowledgement. All these duration will be added to the packet duration to get the mean duration of the "slot" that is used in our model, see figure 5. Actually as far as the throughput is concerned all these overheads can been summarized by a multiplication factor applied to the air rate W simply derived by a rule of three. However this model does not take into account collision of network nodes within carrier sense range. For instance it is possible to consider these collisions by using a model similar to the CSMA model described in [1]. The dominant factor is shown to be the ratio of the propagation delay plus detection time of a packet sent by a node to one of its neighboring nodes and of the transmission delay of a packet. We will summarize the effect of the "within carrier sense range collisions" and of the other overhead by a multiplication factor $C^s_{max}(csma)$ this factor can be seen as the normalized throughput if the network was a single hop network, thus the maximum achievable throughput in a single hop network will be WC^s_{max}

To compute the network throughput of our CSMA ad hoc network we have to estimate the maximum number of simultaneous transmissions in our ad hoc network with respect to the carrier sense range R_{cs}. It is easy to compute this figure if the transmitters are in a regular pattern on a grid or on equilateral triangles. For the grid we find $\frac{S}{R^2_{cs}}$ and for the tessellation with equilateral triangles it is $\frac{S}{\frac{\sqrt{3}}{4}R^2_{cs}}$. The Matern hard-core process [19] allows one to build starting for a Poisson process point a derived process where two nodes are bound to be R_{cs} apart. To construct it, one gives marks $m(x)$ to the initial Poisson process. The marks will be a random number uniformly distributed over (0,1). The Matern hard-core is a thinned process derived by selecting the nodes with the smallest mark within a disc of radius R_{cs}. The obtained process will have the property that two points of this

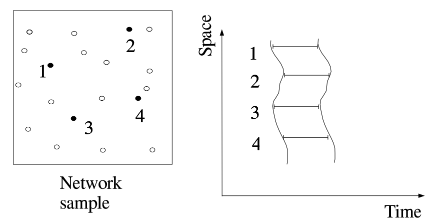

Figure 4: A sample of the network transmissions

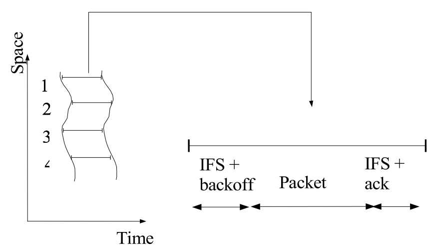

Figure 5: Slot time in our model

process are at least R_{cs} apart. An interesting feature is that it is possible to compute the intensity of the Matern hard-core process. This intensity $\lambda_{R_{cs}}$ is $\lambda_{R_{cs}} = \frac{1-e^{-\pi\lambda R_{cs}^2}}{\pi R_{cs}^2}$ see [20].

In the following we can assume that the derived process of the actually transmitting nodes in a CSMA network can be approximated by a random pick algorithm. Points in the initial Poisson process are chosen at radom but the constraint that no other selected points are within R_{cs} of a new selected point.

The Matern hard-core does not exactly correspond to our CSMA random pick model as it could be thought at the first glance. Let us imagine a random pick model based on the shortest backoff time in a disk of range R_{cs}; this model is the direct line of a real CSMA protocol. Let us suppose that the mark used in the Matern hard-core by a point (representing a network node) is the inverse of the selected backoff time. Thus a selected node is the node with the smallest backoff time which is exactly CSMA. However when nodes have already been eliminated by a selected node they should be removed from the process to carry on the node selection. This step is not included in the Matern hard-core process which explains why the Matern hard-core does not exactly correspond to our CSMA random pick model. It can also be noticed that the number of CSMA elligible nodes in a regular network or selected by a Matern hard-core process varies with $1/R_{cs}^2$. We will thus assume and verify by simulation that the number of nodes in random CSMA selection is thus $F(R_{cs})/R_{cs}^2$, $F(R_{cs})$ will be a constant when R_{cs} is not to small and $F(R_{cs})/R_{cs}^2$ will be equivalent to λ for small small R_{cs}. We can thus assume that the maximum number of possible simultaneous transmission is given by $\frac{SF(R_{cs})}{R_{cs}^2.}$ To capture the total throughput of the network we have to take into account the success rate of a transmission. Let us denote by C_{csma} the average collision rate of a transmission in our ad-hoc network given that at least two colliding nodes are not within carrier reach. The number of transmission free of hidden collisions is thus $\frac{SF(R_{cs})(1-C_{csma})}{R_{cs}^2}$. To complete our evaluation we have to take into account all the network overheads that have been described above. We have shown a simple rule of three can be applied. The global throughput of the network (including the relayed packets) is thus:

$$\frac{SWC_{max}^s(csma)F(R_{cs})(1-C_{csma})}{R_{cs}^2.}$$

To compute the actual throughput of the network, we would have to make an assumption concerning the average length in number of hops L between a given source and the related destination. However we intend only to compare global throughput of CSMA and of Aloha in multihop networks thus the above formula will give us enough information. From the above formula we see that R_{cs} can be used to optimize the global throughput. Obviously we have to find the good tradeoff. On the one hand, with a small R_{cs} we will allow more nodes in the network to transmit. In the other hand if R_{cs} is small the number of collision from nodes not within carrier sense reach will be higher. We fix the transmission range R to ensure the network connectivity using the results from [21].

It must be well noted that the previous model does not consider any collision on the acknowledgement packet. The implicit assumption is that when there is no collision on the transmitted packet, the acknowledgement packet is also collision free.

3.3 Model for Aloha

We are considering a simple Aloha protocol where network nodes are using a constant transmission probability p to rule the packet transmissions. To present the best performance for Aloha, we will assume that the protocol is slotted. This assumption also allows us to acknowledge the packet at the MAC level. The slot will therefore encompass the data packet itself and the acknowledgement packet sent by the destination node if this latter has properly received the packet. The number of simultaneous transmissions in the network can be easily evaluated: it is Sp and the obtained throughput is therefore $Sp(1-C_{aloha}(p))$. As in CSMA we can use a rule of three to take into account the overhead thus the network total throughput (including relayed packets) is given by $SWC(aloha)p(1-C_{aloha}(p))$ where $C(aloha)$ denotes the fraction of the slot used by the data packet. p will be used to optimize the throughput as done in [3].

3.4 Results of CSMA and Aloha models

It does seem possible to obtain close formulas for the previous two models. For Aloha, the throughput can be exactly computed (close formula) if the transmission power is exponentially distributed see [22], but the same result can not be obtained with constant transmission power. For CSMA a close formula does not seem to be within reach since there is no known formula for a shot noise of points in an hard core process. That is the reason why we use a static simulation to evaluate C_{csma} and $C_{aloha}(p)$.

Without loss of generalities, we will assume that the transmission range is 1. To ensure a proper connectivity of the network, we will choose a network density for which the network is connected with a high probability. Results from [21] are used to compute this network density. Of course either the transmission range or the network density can tuned to ensure this property.

As already stated, Aloha and CSMA must be first optimized versus respectively the carrier sense range for CSMA and the transmission probability for Aloha. In the figure 6 below we give the optimized carrier sense range for various value of α in the two models of the strongest interference and the total interference. In the figure 6 below we give the optimized carrier sense range for various value of α in the model of the total interference. Figure 7 below, reports the optimized value of p. In order to present results independent

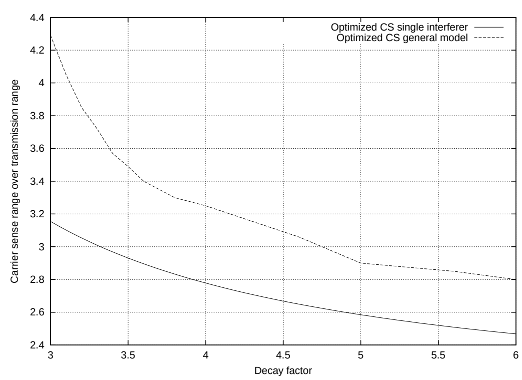

Figure 6: Optimal R_{cs}/R for CSMA and α between 3 and 6, $K = 10$ dB

of the network node density i.e. λ, results given in 7 reports the optimum transmission density i.e. λp both for a constant transmission power and for an exponentially distributed transmission power. For this latter case, results can be found in [22].

We now have the parameters to optimize Aloha and CSMA. The model described above allows one to compute the throughput for CSMA and slotted Aloha. Figure 8 presents the density of successful transmissions for CSMA and slotted Aloha. The conditions for these results are a capture parameter $K = 10$ dB and a transmission decay α between 3 and 6. Figure 9 reports the ratio between the density of successful transmission for CSMA and

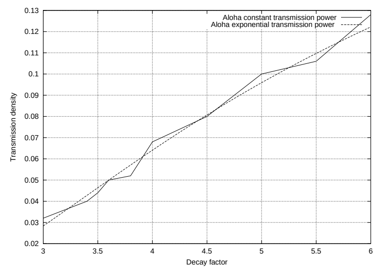

Figure 7: Optimal transmission density for slotted Aloha and α between 3 and 6, $K = 10$ dB

for Aloha. It can be seen that this ratio decreases nearly linearly with α between 2.6 and 1.6 when $T = 10$ dB and between 3.3 and 2.6 when $T = 15$ dB. For small values of T the results are found to be close to the case $T = 10$ dB. This result shows that despite the possible effect of hidden collision, CSMA does offer superior performance than slotted Aloha in a multihop network. This result is not corrected by the overhead $C^s_{max}(csma)$ and $C(aloha)$. It may be assumed that the overhead resulting from the acknowledgement packet and MAC encapsulation is equivalent for CSMA and for Aloha. For CSMA we have to consider the effect of collision for transmission within carrier sense reach. The model derived in [1] offers a good approximation to evaluate this effect; the correcting factor is found to be $1/(1+2\sqrt{\delta})$ where δ denotes the ratio between the detection plus propagation time and the duration of the packet transmission. With this formula, a complete comparison can be obtained whenever all the parameters are known. Considering results of figure 9, CSMA will outperform Aloha in a large number of configurations.

Results of figure 9 seem in contradiction with previous results from Nelson and Kleinrock [3]. In [3] it is shown that CSMA and Aloha offer similar throughput in a multihop network contrary to what is known to be in usual single hop radio network. The difference between the two results can be explained by the different models used in the two approaches. In [3] the assumption is that the interference propagates at two hops thus when a transmitter A is chosen a new transmitter must be selected at least at three hops from A. It means that the carrier sense range used in [3] should approximately be twice the transmission range. As a matter of fact [3] shows that the mean distance between nodes three hops away is twice the transmission range. However we have seen in figure 6 that a larger carrier sense range is required to optimize the throughput. This is certainly the reason motivating the different results of the two works. With the tuning adopted in [3] there is a non negligible probability of hidden collision (actually computed in [3]) as the carrier sense range we adopt in this work to optimize the throughput of CSMA actually avoids any hidden collision.

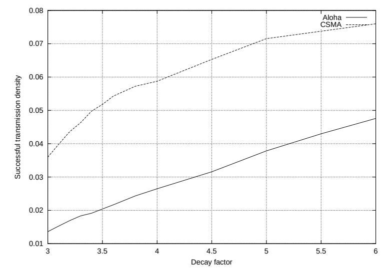

Figure 8: Transmission density for CSMA and slotted Aloha, α between 3 and 6, $K = 10$ dB

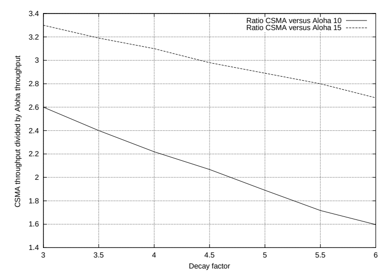

Figure 9: Transmission density for CSMA and slotted Aloha, α between 3 and 6, $K = 10$ dB and $K = 15$ dB

4 Simulations results

The goal of this part is to compare results of the models with simulation results. The parameter of the simulation are the following :

- the network encompasses 100 nodes randomly positioned on a square $2000m \times 2000m$.
- transmission range is set at $R = 250$ m,
- the air rate is 2 Mbit/s,
- the traffic is Poisson and symmetric on all the network nodes, the packet size is 12000 bits.

Above is a list of items which could motivate difference between the model and simulation results :

- CSMA is not slotted in the simulation,

- the simulations are a using a real carrier threshold and not the simplified model with a radius of carrier sense range,
- contrary to the simulation model for CSMA uses a "real" backoff technique,
- for CSMA the simulation is mixing "usual" collisions with "hidden" collision,
- the geographic extension of the network is not infinite and thus we have edge effects.

For $\beta = 3$ and $K = 10$ dB, we draw 10 different random topologies. We are comparing the maximum global throughput for CSMA and Aloha. The results are presented in figure 10. These simulations are not taking into account all the MAC overhead and the overhead generated by the MAC acknowledgement. For CSMA we have taken into account the correcting factor $1/(1 + 2\sqrt{\delta})$. We observe that the simulations are reporting results close to those of the models. However the models are slightly favoring CSMA over Aloha. The fact that the CSMA model is using an optimistic evaluation of the cost for the back-off scheme can probably explain the discrepancy between the simulation results and the results of the models. In the simulations the optimization with respect to the carrier sense threshold for CSMA and for the transmission probability p for Aloha are well predicted by the models (error less than 10%).

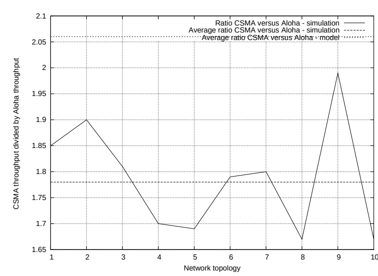

Figure 10: Ratio of the transmission density for CSMA and of slotted Aloha, $\alpha = 3$ for 10 different topologies, $K = 10$dB

In figure 11 we are reporting similar results with a varying decay rate. We have similar conclusions.

We have shown that CSMA offers a higher throughput than Aloha in a multihop network. However the discrepancy between the two protocols throughput would probably be reduced if the simulations were carried out with a routing protocol. As a matter of fact at high load, there is a high probability of losing routes. This effect may cause a lot of packet loss and may reduce the actual difference between the two protocols.

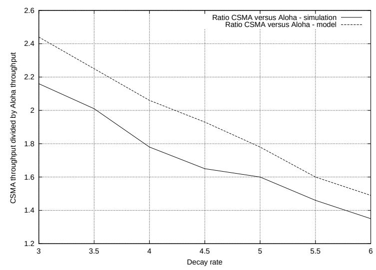

Figure 11: Ratio of the transmission density for CSMA and of slotted Aloha, α between 3 and 6, $K = 10$ dB

5 Conclusion

In this article, we have compared the maximum throughput of CSMA protocols with Aloha in multihop adhoc networks when the radio propagation is isotropic without obstacles. When CSMA and Aloha are optimized both models and simulation results show that CSMA outperforms Aloha. This result seems in contradiction with a previous study [3] but the reason of these diverging results have been identified. CSMA has not been optimized in [3] as in this paper the convenient optimization has been carried out.

References

[1] D. Bertsekas and R. Gallager, *Data Networks*. Prentice Hall, 1988.

[2] F. Tobagi and L. Kleinrock, "Packet switching in radio channels part II - the hidden terminal," in *IEEE transactions on Communications*, 1975, pp. 23(12):1417–1433.

[3] R. Nelson and L. Kleinrock, "Maximum probability of successful transmission in a random planar packet radio network," in *Proceedings of IEEE INFOCOM 1983*, San Diego, April 1983.

[4] "IEEE 802.11 standard. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications," 1997.

[5] "ETSI *HIPERLAN functional specifications*, ETS 300-654," June 1996.

[6] C. E. Perkins, E. M. Royer, and S. R. Das, "Ad hoc on-demand distance vector (AODV) routing," Internet Draft, draft-ietf-manet-aodv-13.txt, February 17 2003, Work in progress.

[7] J. G. Jetcheva, D. Johnson, D. Maltz, and Y. Hu, "Dynamic source routing (DSR)," Internet Draft, draft-ietf-manet-dsr-08.txt, February 24 2003, Work in progress.

[8] R. Ogier, M. Lewis, and F. Templin, "Topology dissemination based on reverse-path forwarding (tbrpf)," Internet Draft, draft-ietf-manet-dsr-07.txt, March 3 2003, Work in progress.

[9] C. Adjih, T. Clausen, P. Jacquet, A. Laouiti, P. Minet, P. ul Muhlethaler, A. Qayyum, and L. Viennot, "Optimized link-state routing protocol," draft-ietf-manet-olsr-08.txt, March 3 2003, Work in progress.

[10] P. Karn, "MACA – a new channel access method for packet radio," in *Amateur Radio Ninth Computer Networking Conference*, 1990, pp. 134–140.

[11] V. Bhargavan, A. Demers, S. Shenker, and L. Zhang, "MACAW: A media access protocol for wireless LANs," in *Proc. of ACM SIGCOMMM 94*, 1994, pp. 212–225.

[12] Talucci and M. Gerla, "MACA-BI (MACA by invitation). a wireless MAC," in *Proc. of IEEE ICUPC 97*, 1997.

[13] J. Deng and Z. Haas, "Dual busy tone multiple access (DBTMA): A new medium access control for packet radio networks," 1998. [Online]. Available: citeseer.nj.nec.com/deng98dual.html

[14] J. J. Garcia-Luna-Aceves and C. L. Fullmer, "Floor acquisition multiple access (fama) in single-channel wireless networks," *Mobile Networks and Applications*, vol. 4, no. 3, pp. 157–174, 1999.

[15] P. Gupta and P. R. Kumar, "The capacity of wireless networks," *IEEE Transactions on Information Theory*, vol. 46, no. 2, pp. 388–404, 2000.

[16] G. Mergen and L. Tong, "Capacity of regular ad hoc networks with multipacket reception." [Online]. Available: citeseer.nj.nec.com/mergen01capacity.html

[17] J. Li, C. Blake, D. S. J. D. Couto, H. I. Lee, and R. Morris, "Capacity of ad hoc wireless networks," in *Mobile Computing and Networking*, 2001, pp. 61–69. [Online]. Available: citeseer.nj.nec.com/li01capacity.html

[18] "The network simulator - ns-2." [Online]. Available: http://www.isi.edu/nsnam/ns/

[19] B. Matern, "Meddelanden fran statens," *Skogsforskningsinstitut 49,5*, vol. 2, pp. 1–144, 1960.

[20] D. Stoyan, W. Kendall, and J. Mecke, *Stochastic Geometry and its Applications.* Chichester: Wiley, 1995.

[21] D. Blough, M. Leoncini, G. Resta, and P. Santi, "The k-neigh protocol for symmetric topology control in ad hoc networks," in *in Proceeding of ACM Mobihoc*, 2003, pp. 141–152. [Online]. Available: citeseer.nj.nec.com/568920.htm

[22] F. Baccelli, B. Błaszczyszyn, and P. Muhlethaler, "An aloha protocol for multihop mobile wireless networks," in *41th ALLERTON Conference*, October 2003.

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